A SOFTWARE DEFINED RADIO BASED ARCHITECTURE FOR THE REAGAN TEST SITE TELEMETRY MODERNIZATION (RTM) PROGRAM

David Ardrey, Gregory Gimler, Mark Pippitt *

MIT Lincoln Laboratory
Lexington, MA

ABSTRACT

MIT Lincoln Laboratory has developed a Software Defined Radio based architecture for the Reagan Test Site Telemetry Modernization (RTM) program, which will enhance the current operations of the ground based telemetry systems and enable new modes of operation.

There are three main objectives of the RTM program; increasing overall system performance, improving reliability and maintainability, and enabling future customer needs.

RTM provides a fully integrated system that can be configured and remotely controlled from a single location. This centralized command and control provides a way to automate certain functions and frees up operator resources, especially for more complex mission scenarios.

Software modules, running on general-purpose computers perform signal and data processing that have been traditionally performed in special purpose hardware based components. This provides the flexibility to scale and adapt to future needs, such as spectrum change, increased need for capacity, and changes to modulation, encoding, and compression.

Index Terms - Software Defined Radio (SDR), Open systems architecture, telemetry receiver architecture, Aeronautical Mobile Telemetry (AMT)

1. INTRODUCTION

The basic challenges present for today's telemetry systems have not changed significantly from challenges faced in the past. First, the demand for frequency spectrum continues to grow at the same time that available spectrum for telemetry purposes decreases. Increasingly complex tests are being executed with more sensors and higher throughput links on test platforms and are quickly using up available spectrum. The national need in the commercial sector with emerging technologies such as 5G is pushing for spectrum reallocation. A system design that is frequency agile and agnostic could adapt to these changes while being minimally impacted by a future change in spectrum assignment or modulation schemes and would save time and money during the transition. [1]

Software-defined radio is a radio communication system where components that have been typically implemented in hardware (e.g. mixers, filters, amplifiers, modulators, demodulators, detectors, etc.) are instead implemented by means of software on a personal computer or embedded system [2]. The SDR architecture of the Modernized Telemetry system replaces much of the traditional specialized hardware with commodity hardware and configurable software modules that perform the telemetry processing functions. This also reduces the amount of frequency specific hardware and helps to reduce the amount of hardware impacted by any possible future spectrum realignments.

2. MODERNIZED ARCHITECTURE

The modernized Telemetry system is based on an open system architecture and distributed system approach. Commercial off the shelf (COTS) Receiver modules are used to perform the RF down conversion, wide band tuning, digitization, narrow band channelization, filtering, and resampling functions. Commodity servers running on standard Operating Systems are used to perform processing, recording and data routing functions. Software Defined Radio processing techniques are used to perform signal processing such as combining, demodulation, bit recovery and decommutation. Signal processing algorithms written in modern software languages are used to perform the traditional telemetry function, but can be easily tailored to enable rapid transition to new mission requirements.

Since the system is network based, it performs as a true distributed system as illustrated in Figure 1. The receiver subsystems can be located at the antenna sites, the signal processing can be performed in a centralized processing center, and the command, control and display functions can be performed from a remote Operations center. Authorized users and maintainers can access the system from any location on the wide area network and mission displays and data products can be sent to remote customers over the network using protocols such as TM over IP (TMoIP).

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In addition, most command, control and configuration tasks can now be automated. Mission configurations can be developed, stored in a centralized database, and later recalled without the need for traditional patch panels and equipment front panel settings.

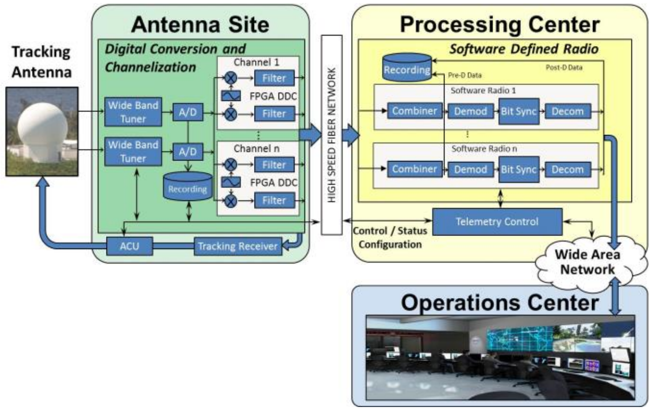

Figure 1 – RTM Distributed System Simplified Block Diagram

2.1. Open Systems Architecture

An Open Systems Architecture (OSA) is one in which all of the interfaces are fully defined, available to the public, and maintained according to a group consensus. One approach to achieve this is to use modular hardware and software and to buy commercial, off-the-shelf and commodity hardware. Benefits of an OSA include providing easy access to the latest technological advances in both hardware and software, enabling net-centric operations, and allowing a flexible design that can easily change as the needs of customers may change. [1]

To maximize flexibility of the RTM system and to leverage the significant advances in modern computing hardware much of the radio functionality traditionally done in special purpose hardware (e.g., combining, demodulation, synchronization) is implemented in software. The processing software uses the Real-Time Open Systems Architecture (ROSA) II [3, 4] an open systems software framework which provides a high performance communications infrastructure that is both hardware and operating system agnostic. This framework enables modularity in the code, empowering the system developer and maintainer to focus on the details of the algorithm implementation.

The Lincoln Laboratory developed ROSA II is a component based architecture designed for implementing real-time sensor systems. The ROSA II architecture allows a given system to be either distributed across a set of processors, computers, or run on a single processor, depending on the needs of that system. [4]

A key aspect of ROSA II is a focus on decomposition and interfaces, which provides maximum flexibility in developing and maintaining a system. This decomposition provides loosely coupled operational subsystem components that, when tied together using well-defined interfaces form a complete sensor processing and control system. Building blocks can be easily added or modified to allow new technology insertion, with minimal impact on the other elements of the sensor system. More importantly, existing building blocks can be shared and used to create new sensor systems or to modernize existing systems. [5]

The underlying concepts of ROSA II are applicable to all types of sensor systems, and have been successfully implemented for both radar and optic sensor upgrades at RTS and on other sensors systems around the world.

3. FRONT END PROCESSING

The RTM Front End for each Telemetry Antenna is composed of a receiver subsystem which includes COTS Receiver modules and a Front End Server. The antenna feed provides two radio frequency (RF) outputs that provide right-hand circular polarization (RCP) and left-hand circular polarization (LCP) signals. These signals are amplified by low noise amplifiers to ensure a good signal-to-noise ratio (SNR). The output from the low noise amplifiers are connected to a wideband receiver subsystem which consists of four identical receiver modules as shown in Figure 2.

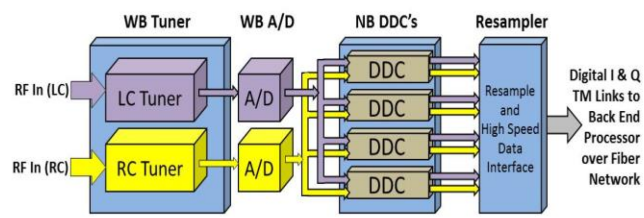

Figure 2 – RTM Receiver Block Diagram (1 of 4 identical units per antenna)

Each receiver module has a pair of wideband tuners whose center frequency can be individually tuned across a broad RF spectrum (0.1 to 6000 MHz) and are each capable of capturing a 60 MHz wide band. The tuner then block converts an entire segment of the band to a common IF. A 16 bit A/D converter samples the tuner block converted output at 250 Msps. One tuner and A/D converter in each module is dedicated to process the right-hand circular polarization and the other is used to process the left-hand circular polarization signals. In this configuration the modernized Front End can support an instantaneous bandwidth of up to 240 MHz. [6]

The digitized signal from the A/D converters are then sent to an on-board FPGA which further down converts and filters each individual telemetry signal within that 80 MHz band using Digital Down Conversion (DDC) techniques. The DDC's are fully configurable as to their center frequency within the 60 MHz band, bandwidth, sample rate

and additional filtering parameters to match the anticipated telemetry link specifications. An arbitrary re-sampler block in the FPGA converts the data rate into an integer multiple of the bit-rate of the signal for use in the demodulator. These parameters are derived from a central configuration database, but can also be adjusted by the system user.

The data interface within each receiver module then transfers each re-sampled data stream into the memory space of the Front End Server by means of Direct Memory Access (DMA) where it is formatted and recorded. The Front End recording is done in a raw binary data format and used primarily for mission assurance purposes. In the event of a network dropout the raw data could be recovered and post processed later. The Front End Server also sends selected data stream across a high speed network link to the centralized telemetry processing center where it is made available to any number of back end processing servers for signal processing.

4. BACK END SIGNAL PROCESSING

The RTM Back End servers perform the traditional Telemetry functions such as Combining, Pre-D Recording, Demodulation, Bit Synchronization, Post-D recording, and Decommutation in software. The Back End server can host several processing chains each representing one Telemetry link.

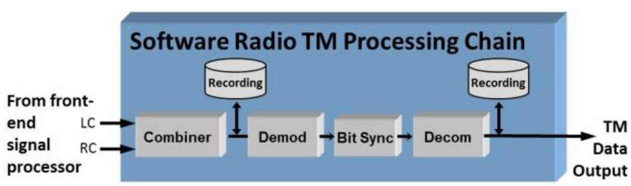

Figure 3 – Back End Signal Processing Chain

The Back End server also formats the output data into protocols such as TMoIP packets to provide decommutated data and displays to both local and remote customers over the Wide Area Network.

As all data is network based, the connections between Receiver Front End and the Back End Processing servers are done via network routing which fully eliminates patch panels. Signal assignments, which mate a particular data stream from a particular Front End Server at the Antenna Facility to a particular processing chain in one or more of the Back End Servers located at the Processing Center, are fully configurable and stored in the central database.

4.1. Polarization Combiner

The first stage in the back end processing chain is the Polarization Combiner which combines the right and left-hand circular polarization data streams and produces a combined data stream of digital complex samples at baseband. This process also compensates for any non uniformity or drifting frequency differences between the LC and RC channels.

The polarization combiner is implemented using blind channel estimation subspace methods similar to the approach described in [7]. The receiver modules share a common local oscillator (LO) so frequency and time compensation is not necessary when combining signals from a single aperture with the same receiver.

4.2. Demodulation / Bit Synchronization

The system is designed to demodulate Advanced Range Telemetry (ARTM) Tier 0 (PCM/FM), Tier I (SOQPSK-TG), and Tier II (Multi-h CPM) waveforms [8] but other advanced modulation schemes could be supported by including additional processing blocks.

In the modernized system, the demodulation and bit-synchronization are performed as a single function. A multiple-bit trellis detection algorithm [9] is used in conjunction with bit synchronization using an early late gate time offset tracker.

4.3. Decommutation

The decommutator is implemented as an integrated software component in the SDR framework. It is responsible for data extraction from the incoming bit stream and ensuring that all telemetered data is available for the required external interfaces. All configuration data is stored in a centralized database in the form of “mission decks” which can be recalled and modified to support similar mission scenarios.

4.4. Data Recording

With the architecture of the network and software framework, the data are available at any point in the processing chain for recording. Raw data from the Front End servers can be reprocessed or used for mission training and simulation. The traditional Pre-D and Post-D recording formats can be selected in real time, and the recorded data can be reformatted into special customer defined recording formats post-mission.

4.5. Remote Control and Centralized Configuration

Due to the distributed architecture of the modernized system, Control and Displays can be hosted at any location on the network. User displays can be tailored for their intended use. For example calibrations and monitoring displays for the calibration technicians and maintainers, displays which show data quality and detailed system metrics for the Telemetry Engineers, and specialized mission level displays for mission operators. The RTM system can be controlled from the RTS Operations Control Center in Huntsville, AL.

Configuration of the system can be changed on the fly via software. A construction of the software radio chains can be specified via a configuration display and saved or loaded prior to an operation. Modules are arranged in a flow graph based description that specifies link parameters, component communication information, and which machine(s) to run the software on. An operator can recall that configuration at any point, reducing the possibility of errors.

5. NEW CAPABILITIES

As the number of telemetry links grow and the bandwidth requirements increase for complex Aeronautical Mobile Telemetry (AMT) missions more reliable and robust links are needed. A robust link operating in co-channel interference could go a long way toward alleviating the shortage of available bandwidth. In addition, hypersonic and autonomous vehicles present challenges that can be mitigated through a more reliable link, particularly when the signal is experiencing multi-path fading.

The open and distributed nature of the RTM architecture enables new capabilities. One example of new capabilities enabled by the RTM architecture is multi-antenna combining prior to demodulation. The combined signal is guaranteed to improve upon the performance of any single antenna and provide reliable link reception even in the presence of interference and multi-path fading. [7]

Since the raw data outputs of each antenna site are available at the centralized processing center, the combined signal from multiple antennas may be computed as a time varying weighted sum of digital I and Q samples from multiple and spatially diverse antennas to produce a multi-aperture product. Instead of just determining the best antenna source to use, the products of multiple antennas can produce a "better than best" choice.

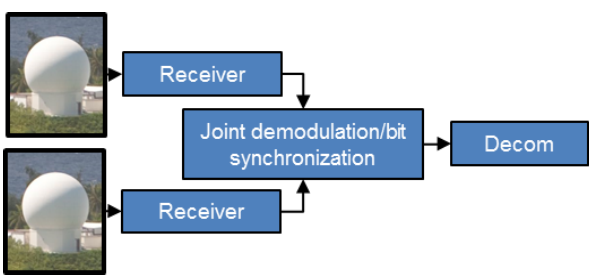

Figure 4 – Multiple Aperture Combining

6. NEW MISSION AREA SUPPORT

The entire sensor suite at the Reagan Test Site, which includes high precision radar, optics and now modernized Telemetry sensors are based on a common Command and Control architecture which allows these sensor types to be used in concert in locating and tracking targets of interest. Since each of these sensor types can produce and share their data products in a common format in real time over a wide area network, this data can then be fused to produce a "super-set" data product. The strong points of each sensor type can be leveraged, such as the accurate range resolution of a radar sensor, the accurate angle information derived from an optics sensor and now the emitted RF signature of the target of interest from the telemetry system. [10]

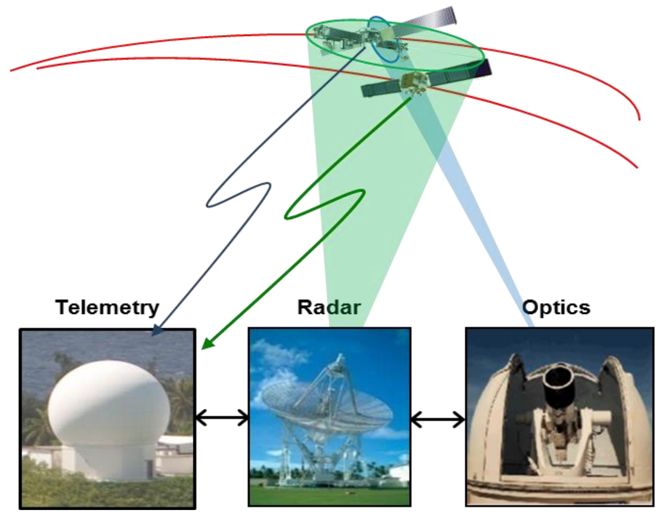

Figure 5 – Multi-Sensor Fusion for Enhanced Target Identification

Telemetry ground stations spread over geographically diverse areas are well suited for use in passively locating the source of a distant transmitted signal using the time-difference of arrival (TDOA) and frequency-difference of arrival (FDOA) techniques. [11] By incorporating the received data from multiple receive sites, the accuracy of these passive localization techniques can compete with the accuracy of radars. As the data products of the modernized telemetry system are time stamped using GPS and available on a wide area network, the outputs of each receiving station can be gathered, time aligned and processed in near real time to determine the physical position of the emitter.

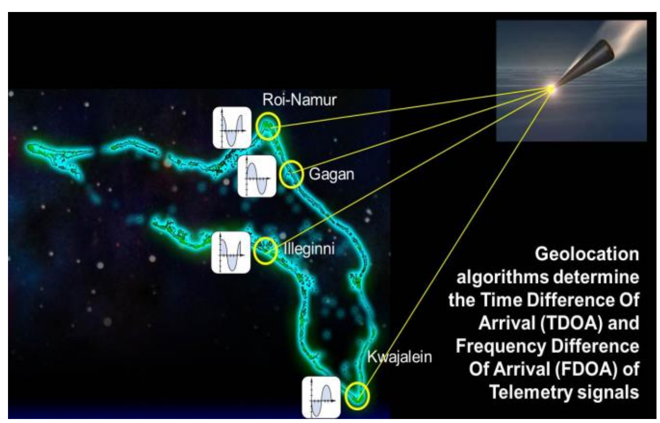

Figure 6 – Passive Emitter Geolocation using TDOA and FDOA Techniques

7. SUMMARY

The modernized telemetry systems as described incorporates state-of-the-art Software Defined Radio and Digital Signal Processing technologies which provides a fully configurable system architecture to ensure the Range capabilities remains viable during the evolution of telemetry frequency spectrum allocations and emerging customer requirements, and position RTS to efficiently maintain and remotely operate ground based telemetry systems from CONUS.

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